BELLCOMM, INC.

SUBJECT: Safe Distance for the ALSEP Emplacement - Case 340

DATE: August 22, 1968

FROM: G. K. Chang

ABSTRACT

Calculations show that the ALSEP can be deployed 80 ft from the LM without experiencing a significant aerodynamic heating effect or receiving detrimental exhaust gas pressure. These calculations are conservative in that the ALSEP is assumed to be directly impinged by the main stream of the ascent engine exhaust gas. A more realistic calculation would give a safe distance for the ALSEP deployment considerably less than 80 ft from the LM.

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MEMORANDUM FOR FILE

Recently a question was raised concerning the distance from the LM at which an ALSEP may be deployed without experiencing detrimental heating or pressure effects from the ascent-engine gas impingement.

This distance, nominally assumed to be 300 ft, is critical on an early mission where astronaut EVA may be restricted. One study (Ref. 1) indicated that the ALSEP would have to be deployed 500 ft away in order not to be unduly heated. The author has made calculations and found that the ALSEP can be deployed 80 ft from the LM without experiencing a significant aerodynamic heating effect or receiving detrimental gas pressure. Dust accumulation on the ALSEP is not considered here. These calculations are conservative in that the ALSEP is assumed to be directly impinged by the main stream of the ascent engine exhaust gas. In the actual mission, the main jet stream impinges directly on the LM descent stage and is then deflected horizontally along the lunar surface. The gas expansion outward along the lunar surface is considerably larger than the expansion directly along the centerline of the main stream. A more realistic calculation would give a safe distance for the ALSEP deployment considerably less than 80 ft from the LM.

The following computations show how the above conclusion is derived.

1. Consider an adiabatic expansion of the exhaust gas in the vacuum. The Mach number of a free expanding jet along the centerline of the stream is given by (Ref. 2),

$$M = A(L/d)^{\gamma-1} - 1/2\left(\frac{\gamma+1}{\gamma-1}\right)/\ A(L/d)^{\gamma-1} ,$$

where A is a constant which depends on the ratio of specific heats, γ, L is the distance from the engine to the point of interest, and d is the diameter of the LM ascent engine orifice.

2. Once the Mach numbers are known along the stream line, one can easily compute temperatures, pressures, densities and velocities of the adiabatically expanding gas with the well known equations given by (Ref. 3),

$$\frac{T}{T_c} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-1},$$

$$\frac{p}{p_c} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-\gamma/\gamma-1},$$

$$\frac{\rho}{\rho_c} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{-1/\gamma-1},$$

$$\frac{V}{a_c} = M\left(1 + \frac{\gamma-1}{2} M^2\right)^{-1/2},$$

where T_c, p_c and ρ_c are the chamber temperature, pressure, and density, respectively, and a_c is the speed of sound in the gas in the chamber which is given by $\sqrt{\gamma R T_c}$.

3. The results of the computation of temperatures and pressures vs. deployment distance are plotted in the attached figure for the LM ascent engine having the following characteristics (Ref. 4):

$T_c = 5{,}100.°R$

$P_c = 1.73 \times 10^4$ lb/ft^2

$\rho_c = 2.7 \times 10^{-4}$ lb/ft^3

$\gamma = 1.232$

$A = 3.96$

$d = 2.71$ ft.

As shown in the attached figure, the gas temperature at 80 ft away is only about 580°R (about 120°F) which is about the same as the nominal daytime ALSEP surface temperature. The convective heat transfer between the gas and the ALSEP is given by,

$$q_{conv} = c\rho V\Delta T,$$

where c is the heat transfer coefficient, which is only a few per cent in most cases, ρ is the expanding gas density which is about 2.4×10^{-8} lb/ft^3 at the distance of 80 ft, V is the gas velocity which is about 10^4 ft/sec (fully expanded gas velocity) and ΔT is the temperature difference between the gas and the ALSEP surface which is at most in the order of tens of degrees at the point of interest. It is clear from the above computation, that the maximum heat transfer rate from the gas to the ALSEP is no more than $\sim10^{-3}$ Btu/ft^2-sec which indicates no concernable amount of aerodynamic heating effect on the ALSEP is expected.

Similarly, the gas pressure at 80 ft from the LM is not significant, being $\sim$0.2 lbs/ft^2 or $\sim$.8 lbs for the ALSEP central station. Contrary to the question raised by others (Ref. 1), a small amount of cooling effect on the ALSEP due to the expanding cold gas might take place when the ALSEP is deployed over 80 ft from the LM. The apparent error in Reference 1 was that they did not take into consideration the adiabatic cooling of the expanding gas.

In writing this memorandum, the author benefited greatly from stimulating discussions with C. Wang concerning the jet expansion in vacuum.

G. K. Chang

2015-GKC-kse G. K. Chang

Attachments
References
Figure 1

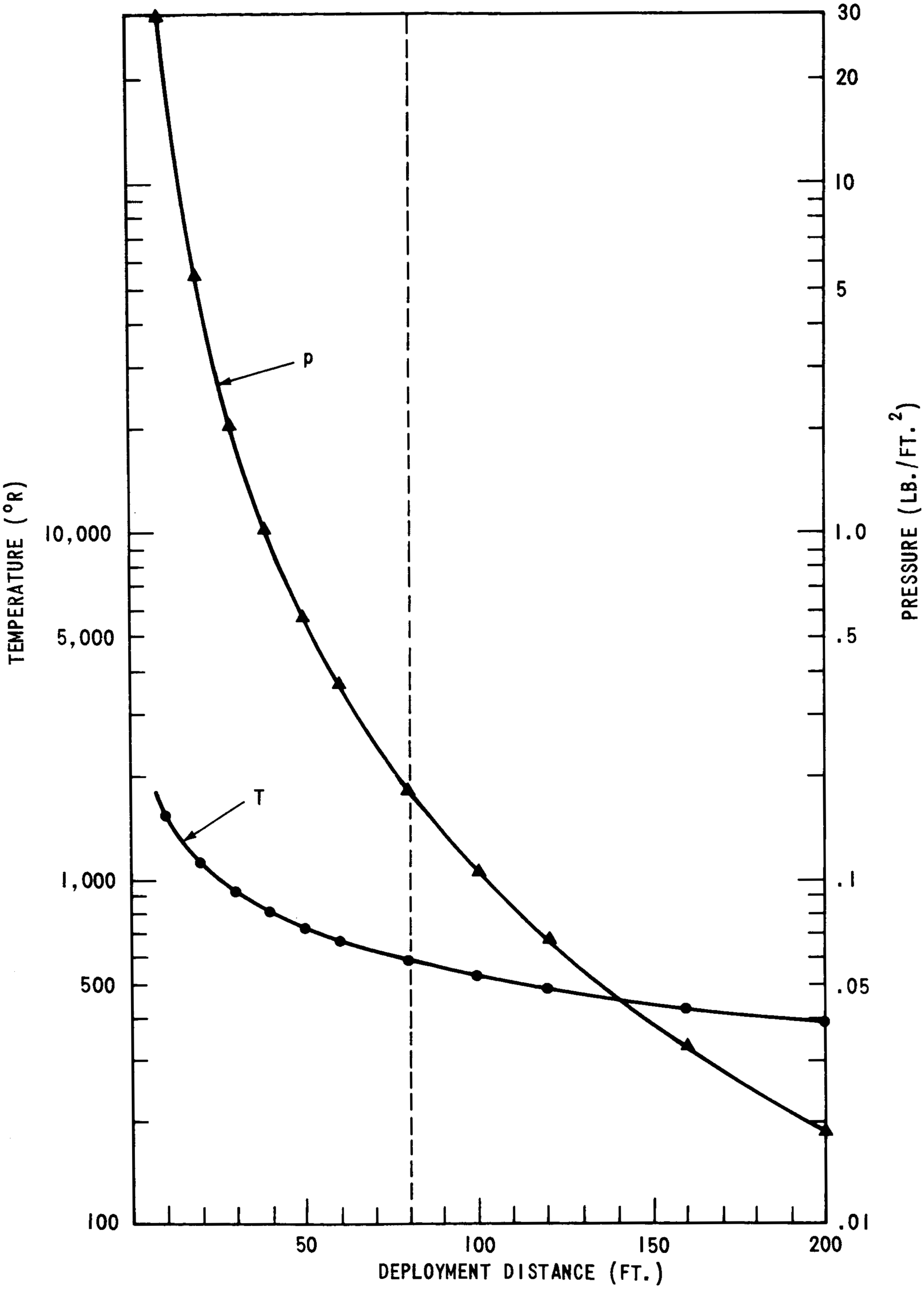
REFERENCES

1. "ALSEP Emplacement Study", Bendix Aerospace, ATM-762, June 1, 1968.

2. Ashkenas, H. and F. S. Sherman, "The Structure and Utilization of Supersonic Free Jets in Low Density Wind Tunnels", in Rarefied Gas Dynamics (J. H. de Leeuw, ed.), pp 84-105. Vol. II, Academic Press, New York (1966).

3. "Equations, Tables, and Charts for Compressible Flow", NACA Report 1135, (1953).

4. "LEM Exhaust Effects", Bendix Aerospace, ATM-295, June 1, 1966.



TEMPERATURE (°R)
10,000
5,000
1,000
500
100
PRESSURE (LB./FT.^{2})
30
20
10
5
1.0
.5
.1
.05
.01
p
T
50
100
150
200
DEPLOYMENT DISTANCE (FT.)

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